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FINAL TECHNICAL REPORT FOR NAG 8-729

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ABSTRACT

We determine x-ray spectral parameters of cataclysmic variables observed with the *Einstein* imaging proportional counter, by fitting an optically thin, thermal bremsstrahlung spectrum to the raw data. Most of the sources show temperatures of order a few keV, while a few sources exhibit harder spectra with temperatures in excess of 10 keV. Estimated 0.1 - 3.5 keV luminosities are generally in the range $10^{30} - 10^{32}$ erg s^{-1} . The results are consistent with the x-rays originating in a disk/white dwarf boundary layer of non-magnetic systems, or in a hot, post-shock region in the accretion column of DQ Her stars, with a negligible contribution from the corona of the companion. In a few objects we find column densities that are unusually high for interstellar material, suggesting that the absorption occurs in the system itself.

I. INTRODUCTION

Cataclysmic variables (hereafter CVs) are binary systems with a white dwarf accreting matter from a late - type companion which overflows its Roche lobe. The origin of x-rays in these systems is still a debated issue. The vast majority are probably disk accretors in which the most likely site for x-ray production is the boundary layer between the inner edge of the accretion disk and the surface of the white dwarf. In the magnetic systems, which make up only a small minority, the most likely site for x-ray emission is the base of the accretion column just above the magnetic poles of the primary. In either case the emission mechanism is thought to be thermal bremsstrahlung from a hot plasma, and the resulting radiation is expected to emerge in the hard x-ray band (where the term "hard x-rays" refers to x-rays with energies of order a few keV, while the term "soft x-rays" will refer to x-rays with energies of order a few tens of eV).

CVs have been surveyed in the x-ray band in small groups with the *Einstein* Observatory (Becker and Marshall 1981, Córdova, Mason and Nelson 1981, Becker 1981) and a number of systems have been studied individually (see review by Córdova and Mason 1983, and references therein). The most extensive study of x-ray spectra of CVs using the *Einstein* Observatory to date is that of Córdova and Mason (1984, hereafter CM) who characterized these stars in terms of their "x-ray colors" and also fitted thermal bremsstrahlung model spectra to the brighter of these sources. When the first papers were written only the original processing of the *Einstein* data was available, and consequently the x-ray spectra of these stars were only described in very crude terms. Now that more extensive information is available on the gain variations in the *Einstein* imaging proportional counter (IPC) it is possible to place much better constraints on the individual x-ray spectra.

Here we determine x-ray spectral parameters of CVs observed with the *Einstein* IPC (for a description see Giacconi *et al* 1979) by fitting a bremsstrahlung spectrum to the raw data, thus extending the work of CM. Limits on the spectral parameters are also given in terms of confidence contours in the temperature – column density plane. In §II we describe the observations and data analysis and in §III we present the results. In §IV we compare the results with predictions of existing models of the accretion process.

II. OBSERVATIONS AND DATA ANALYSIS

The objects studied include 32 individual CVs (non-magnetic and DQ Her stars). Many of these objects were observed more than once, bringing the total number of observations to 51. The data were collected from a circle of radius 3 arcminutes centered on each source and cover the energy range 0.16 - 4.47 keV. The observations contain gaps due to earth occultation, bright earth, high background, bad aspect and, occasionally, bad detector performance. A list of sources together with the details of the observations are given in Table 1.

The observed spectra were fitted with an optically thin, thermal bremsstrahlung model of the form (Rybicki and Lightman 1979)

$$F(E) = A\,(kT)^{-1/2} \quad e^{-E/kT} \quad \bar{g}_{\rm ff}(E,T) \quad e^{-N_H\sigma(E)} \;, \tag{1}$$

where $F(E)$ is the observed flux per unit energy interval, E is the energy of the radiation, T is the temperature of the emitting plasma and k is Boltzmann's constant. A is a normalization constant which includes the density of the plasma, and $\bar{g}_{\rm ff}(\nu,T)$ is a velocity averaged Gaunt factor for free - free emission (see Rybicki and Lightman 1979). The factor $e^{-N_H\sigma(E)}$ takes account of interstellar photoelectric absorption (N_H is the column density of absorbing material in the direction of the source and $\sigma(E)$ is the absorption cross section).

The model spectrum, as given by equation (1) for given values of kT and N_H, was convolved with the detector response function to produce the expected distribution of counts in the IPC energy channels and was normalized so that the total number of predicted counts would agree with the total number of observed counts. For the Gaunt factor we used the polynomial approximation of Kellog, Baldwin and Koch (1975) to the tabulated values of Karzas and Latter (1961) and for the absorption cross section we used the values of Brown and Gould (1970). The observed and predicted count distributions were compared , using the χ^2 test, for a range of values of kT and N_H to produce a grid of χ^2 values in the (N_H, kT) plane.

III. RESULTS

The results of the fitting are presented in Figures 1(a) and 1(b). Each frame shows the best combination of fitting parameters (minimum χ^2) together with 68% (1σ) and 90% (1.6σ) confidence contours in the (N_H, kT) plane. The 68% and 90% confidence regions are the regions of χ^2 within 2.3 and 4.6 respectively of the minimum χ^2 (Lampton, Margon and Bowyer 1976; Avni 1976). In Figure 1a the range of the parameters displayed is kT: 0.2 - 20 keV, N_H : $10^{19} - 10^{23}$ cm^{-2}. In Figure 1b the range is chosen independently for each observation to provide the best presentation. The constraints on the spectral parameters (temperature and column density) set by the confidence contours are summarized in Table 2. Table 2 also contains the observed 0.1 - 3.5 keV fluxes implied by the spectral parameters together with estimated luminosities (distance estimates were drawn from Patterson 1984).

The temperatures found are generally higher than 0.3 keV with only a few cases below 1 keV. They nevertheless show a fairly large scatter, which could be attributed to a wide range of accretion rates and white dwarf masses. In 16 observations the temperature of the source is well constrained and falls in the range 0.2 - 20 keV (the best fits are between 1 and 10 keV). The goodness of the fits indicates that the thermal bremsstrahlung model provides a good description of the observed spectra. In another 16 observations, on the other hand, only a lower limit to the temperature is obtained. In these cases, as noted by CM, the IPC is probably detecting the low energy end of a very hard (several tens of keV) spectrum. In four extreme cases

(HT Cas, BV Cen, EM Cyg and WX Hyi) the temperature is unconstrained, in the sense that although χ^2 has a minimum within the range covered by the variational parameters the 68% and 90% confidence contours are open at both high and low temperatures (see Figure 1a).

The 0.1 - 3.5 keV luminosities also show a fairly large scatter, ranging mostly from 10^{30} to 10^{31} erg s^{-1} and for a few systems they become as large as 10^{32} erg s^{-1}. It should be noted that systems with quite high accretion rates ($\dot{M} \gg 10^{16}$ g s^{-1}) also show substantial hard x-ray luminosities (e.g., V603 Aql: $\dot{M} \approx 1.3 \times 10^{18}$ g s^{-1}, $L_x \approx 4 \times 10^{32}$ erg s^{-1}, and GK Per: $\dot{M} \approx 1.1 \times 10^{17}$ g s^{-1}, $L_x \approx 2 \times 10^{32}$ erg s^{-1}; other examples include MV Lyr, V3885 Sgr and RW Sex – $\dot{M}$ values were taken from Patterson and Raymond 1985*a*, hereafter PR).

Column densities of absorbing material are generally in the range 10^{20} – 10^{21} cm^{-2}. These values are consistent with the column density - distance relation for stars within 1 kpc from the sun, inferred from L$_\alpha$ absorption measurements: $< N_H > \approx 1.3 \times 10^{18}$ cm^{-2} pc^{-1} (Bohlin, Savage and Drake 1978) and with HI column densities derived from 21cm measurements (Daltabuit and Meyer 1972; Heiles 1975) implying that the absorption is most probably interstellar. There are, however, four sources (HT Cas, BV Cen, EM Cyg and GK Per) for which the column density is unusually high (around 10^{22} cm^{-2}). Such high values are inconsistent with HI column densities (Daltabuit and Meyer 1972, Heiles 1975) and interstellar reddening and extinction (Lucke 1978, Neckel and Klare 1980) in the directions of these stars, which suggests that the absorption occurs in the source itself. We shall return to this issue in §IV.

The results also indicate significant variability in the spectral parameters of some sources. V603 Aql exhibits a change in temperature by almost a factor of 10 (accompanied by a notable change in x-ray luminosity) within a period of about 4 months. SU UMa shows a decrease in temperature by a factor of 5, accompanied by an increase in the absorbing column density by a similar factor (but apparently no change in luminosity) in observations separated by about 1 year. This variability is also reflected in changes in the "x-ray colors" of this star, as noted by CM. Other examples of variability are seen in HL CMa and EX Hya. HL CMa shows a decrease in temperature by a factor of 2 within a day, accompanied by an increase in luminosity and column density by the same factor (observations I6962 and I6963), while EX Hya exhibits a temperature drop by a factor of 3 and a small decrease in luminosity within a period of 4 days (observations I2268 and I7714).

IV. DISCUSSION

To put the results into perspective, it would be very useful at this stage to review current ideas about x-ray production in cataclysmic binaries. We shall first concentrate on models of x-ray emission due to accretion of matter onto the white dwarf, and then examine the possibility of contributions to the x-ray luminosity from other x-ray sources in the system such as the corona of the companion star.

a) X-Rays due to Accretion

In most systems accretion is believed to proceed through a disk which extends all the way to the surface of the primary. In order to settle onto the surface of the (presumed) slowly rotating white dwarf, the accreting material at the inner edge of the disk must dissipate its kinetic energy and angular momentum. This can be achieved within a thin disk/star boundary layer either through a series of shocks (Pringle and Savonije 1979) or through turbulence (Tylenda 1981). In either case the boundary layer becomes optically thin at low accretion rates ($\dot{M} \leq 10^{16}$ g s^{-1}) and heats up to temperatures of order 10^8K at which it can radiate hard x-rays through thermal bremsstrahlung. At such low accretion rates it is possible for the x-ray emitting plasma to expand out of the plane of the disk and even form a hot corona around the white dwarf (King and Shaviv 1984*a*; King Watson and Heise 1985). About half the accretion luminosity is expected to emerge from the boundary layer.

In systems with fairly strong magnetic fields (DQ Her stars, $B \geq 10^5$G) the magnetic field dominates the flow at small distances from the primary and channels the accreting material through an accretion column onto the magnetic poles of the white dwarf. In these systems the hard x-rays are thought to originate in the accretion column, where a strong shock just above the surface of the star heats the accreting material to temperatures of order 10^8K. At these temperatures the shocked gas can radiate hard x-rays through thermal bremsstrahlung (see review by Lamb 1983, and references therein). Support for this scenario is provided by the detection of optical and x-ray pulsations from these systems, where the pulsation period is identified as the white dwarf rotation period (Osborne 1988; Patterson 1990).

According to the above models we would expect the hard x-rays from CVs to have a thermal bremsstrahlung spectrum with a temperature around a few keV or even higher (a few tens of keV), depending on the white dwarf mass and the accretion rate. For DQ Her stars, where the accretion is radial, we can use equation (3) of Lamb (1983) and the approximate white dwarf mass - radius relation (inferred from Hamada and Salpeter 1961)

$$R \approx 4.9 \times 10^8 \left(\frac{M}{M_\odot}\right)^{-0.8} \text{cm} \tag{2}$$

to estimate the maximum temperature attainable by the x-ray emitting plasma

$$kT = 17.3\ M_{0.7}^{1.8}\ \text{keV}\ , \tag{3}$$

where $M_{0.7}$ is the white dwarf mass in units of $0.7M_\odot$, the average mass empirically determined in CVs (Shafter 1983). For disk accretors the bremsstrahlung temperature of the boundary layer has been estimated by PR to be

$$kT = 1.3\ \frac{M_{0.7}^{3.6}}{\dot{M}_{16}}\ \text{keV}\ , \tag{4}$$

where $\dot{M}_{16}$ is the accretion rate in units of 10^{16} g s^{-1}. PR have also estimated the hard x-ray luminosity expected to emerge in the *Einstein* IPC bandpass to be

$$L_x(0.2 - 4\ \mathrm{keV}) = 8.7 \times 10^{31} \dot{M}_{16}\ M_{0.7}^{1.8}\ \mathrm{erg\ s^{-1}}\ . \tag{5}$$

b) Other X-Ray Sources: Coronal Emission from the Companion Star

The accretion process is not the only source of x-rays in CVs, but the only serious competition is likely to come from the corona of the companion star. The shocked gas in the "hot spot" (where the gas stream from the secondary hits the accretion disk) is also a potential x-ray source but, as pointed out by Pringle (1977), in order to reach the observer the x-rays have to traverse a large thickness of cool material above the shock. As a result they will be severely degraded due to photoelectric absorption and Compton scattering and the "hot spot" will effectively radiate as an optically thick source at temperatures around 10^4K (Bath *et al.* 1974, Tylenda 1977).

The detection of luminous, hard x-ray components in the spectra of RS CVn binaries by Swank *et al.* (1981) ($kT \sim 4$ keV, $L_x \sim 10^{30}$ erg s^{-1}), viewed in the light of the temperatures and luminosities that we find in our collection of CVs, raises the question of whether coronal x-ray emission from the companion star in a cataclysmic binary makes a significant contribution to the x-ray luminosity of the system. Because, as Swank *et al.* (1981) note, part of the x-ray emission in RS CVn systems may be due to a binary interaction that would not be observed in single stars and because it is by no means clear that this type of interaction occurs in cataclysmic binaries it would be more appropriate to examine the x-ray properties of isolated stars in an attempt to assess the contribution of the secondaries to the x-ray emission from CVs. Since CV secondaries are slightly evolved, but otherwise normal late type (G, K, M) main sequence stars (Patterson 1984), we start by considering x-ray luminosities of isolated late type stars. X-ray luminosity functions derived from volume-limited samples observed with the *Einstein* observatory show only 4% of G stars and 9% of M stars having x-ray luminosities in excess of 10^{29} erg s^{-1} and none with x-ray luminosities above 10^{30} erg s^{-1} (Rosner, Golub and Vaiana 1985).

Late type stars also exhibit a correlation between their x-ray luminosity and their projected equatorial rotational velocity of the form $L_x = 10^{27}(V \sin i)^2$ erg s^{-1} , where the rotational velocity is in km s^{-1} (Pallavicini *et al.* 1981). This correlation, however, has been established at low rotational velocities (periods of order days) and probably cannot be extrapolated to high rotational velocities such as those encountered in CVs (periods of order hours). The results of x-ray studies of the Pleiades carried out by Caillault and Helfand (1985) and Micela *et al.* (1985) suggest that the x-ray luminosity – rotational velocity relation flattens out at high rotational velocities ($V_{\rm rot} > 30$ km s^{-1}) at an x-ray luminosity level of about $1 - 5 \times 10^{29}$ erg s^{-1} . This behaviour is also seen in the results of the x-ray survey of rapidly rotating contact binaries (W UMa stars; periods less than 1 day) of Cruddace and Dupree (1984), which has not revealed any stars with x-ray luminosities in excess of 10^{30} erg s^{-1}. More recently Fleming, Gioia and Maccacaro (1989) have suggested, based on their study of a sample of stars from the *Einstein* Extended Medium Sensitivity Survey, that the x-ray luminosity – rotational velocity relation might be due to a more fundamental dependence of x-ray luminosity on radius (the precise functional form of the Pallavicini *et al.* (1981) relation has also been questioned) and that the x-ray luminosity "saturates" at large stellar radii, and they have proposed a plausible saturation boundary described by $L_x = 10^{29}(R/10^5\mathrm{km})^2$ erg s^{-1} .

X-ray temperatures of stellar coronae have very recently been studied by Schmitt *et al.* (1990) using a large sample of stars observed with the *Einstein* IPC. They find that late - type main sequence stars (usually M) always exhibit both a high and a low temperature component (the low temperature component is around 10^6K, while the high temperature component exceeds 10^7K). Earlier type stars (F and G) do not show the high temperature component, and instead their x-ray emission is dominated by plasma at the lower temperature. Except for RS CVn systems the luminosities of stars in this sample are below 10^{30} erg s^{-1}.

Motivated by the x-ray properties of stellar coronae, we have looked for possible correlations between the x-ray spectral parameters of CVs and the properties of the companion stars (spectral type, rotation period, equatorial rotational velocity and radius) as a test of the hypothesis that the origin of x-rays is coronal. We have been able to draw information on 17 of the systems in our collection from Patterson (1984). For systems where the masses of the two components were available, we used the prescriptions given by Patterson (1984) to calculate the radius of the companion. For the other systems, we estimated the radius of the companion based on its spectral type. Information on this subset of CVs is summarized in Table 3. The spectral analysis was repeated for for a Raymond - Smith thermal plasma model, which provides a more appropriate description for coronal sources, and the results (temperatures and 0.1 - 3.5 keV luminosities corrected for absorption) are summarized in Table 4. For the vast majority of observations the confidence contours in the (N_H, kT) plane obtained with the two spectral models (the Raymond - Smith model and the original bremsstrahlung model) overlap almost completely and the minimum values of χ^2 are extremely close. For six observations the goodness of the fit varies considerably between the two models (the minimum values of χ^2 differ and the confidence contours do not overlap). These are the three observations of AE Aqr where the bremsstrahlung model provides a better fit and observations 7714 of EX Hya and 8018 and 8357 of SU UMa where a better fit is obtained with the Raymond - Smith model. In Figure 2 we present plots of 0.1 - 3.5 keV luminosities (corrected for absorption) and spectral temperatures obtained using the Raymond - Smith model versus orbital period, equatorial rotational velocity, radius and spectral type of the companion, which show no apparent correlations. In the plot of x-ray luminosity versus radius we show the saturation boundary suggested by Fleming, Gioia and Maccacaro (1989) and we note that the luminosities we determine fall well above this limit, which argues against coronal emission. In Figure 3 we show the location of the CVs in our collection on the x-ray luminosity vs temperature diagram of Schmitt *et al.* (1990). We note that the x-ray luminosities of CVs and, in many cases also their temperatures, fall substantially above the typical values for main sequence stars (instead they are comparable to or greater than typical values for RS CVn systems). This, together with all the other evidence presented thus far suggests that the x-ray emission we observe in our collection of CVs is primarily due to accretion onto the white dwarf in the system with only a very small contribution from the companion star.

An interesting example which supports the above suggestions is provided by AE Aqr. This DQ Her system has a 0.1 - 3.5 keV luminosity (unabsorbed) of about 7×10^{30} erg s^{-1} which is relatively low compared to that of other CVs in our collection and comparable to luminosity of the hard x-ray component seen in RS CVn binaries (Swank *et al.* 1981). The x-rays from AE Aqr are pulsed with a period of 33 seconds and a pulse fraction of up to 30% (Eracleous, Patterson and Halpern 1991), which indicates that the x-ray source is probably at the base of an accretion column, just above the surface of a rapidly rotating white dwarf. This not only suggests that the accretion process is responsible for the bulk of the x-ray emission, but also argues against the presence of a binary interaction of the type that gives rise to the hard x-ray emission in RS CVn binaries.

Particularly valuable clues about the physical conditions in the x-ray emitting plasma can be provided by high resolution x-ray spectra. Unfortunately there have been very few observations of CVs with a resolution high enough to be of interest (the resolution of the *Einstein* IPC is too poor to detect individual emission lines in the 0.1 - 4.0 keV band). Observations of AM Her with the HEAO-1 A-2 and A-4 experiments (Rothschild *et al.* 1981) and of AM Her, U Gem and SS Cyg with the *Einstein* OGS (Objective Grating Spectrometer; Fabbiano *et al. 1981*) show no emission line features other than the Fe line around 7 keV (HEAO-1 observation of AM Her). In contrast, spectra of Capella and other RS CVn binaries obtained with the *Einstein* OGS and SSS (Solid State Spectrometer) (Holt *et al.* 1979, Swank *et al.* 1981, Mewe *et al.* 1982) show an abundance of emission lines due to heavy elements (such as Fe, O, Mg, Si, S, Ne) in high ionization states, which is also evident in *EXOSAT* spectra (Schrijver 1985). This sparse spectral information seems to indicate that the physical conditions in the x-ray emitting plasmas in CVs and RS CVn systems are quite different – although the temperatures can be comparable (Schmitt *et al.* 1990) – and suggests that coronal x-ray emission from CV secondaries is negligible compared to accretion driven x-ray emission. The dominant excitation mechanism in coronal sources is electron impact excitation, and line emission from heavy ($Z \geq 8$) elements is the dominant cooling process for temperatures between 10^4 and 10^7 K (Holt and McCray 1982). For the shock heated plasma in the vicinity of the white dwarf, however, photoionization is probably also an important process due to the higher density, with the result that many of the heavy elements are fully stripped of their electrons (hence the absence of prominent emission lines). This justifies a preference of a bremsstrahlung model spectrum over a Raymond - Smith model spectrum.

It should be pointed out that although coronal x-ray emission from the companion star might no be important for x-ray bright [L_x(0.1 - 3.5 keV) > 10^{30} erg s^{-1}] CVs it might not be negligible for x-ray faint ones. In systems with low accretion rates ($\dot{M} < 10^{14}$ g s^{-1}) the hard x-ray luminosity due to accretion becomes comparable to the x-ray luminosities of late type stars and the possibility of contribution from the corona of the companion cannot be ignored. The possibility of an interaction between the corona of the companion and the outer edge of the accretion disk similar to what is seen in RS CVn systems, though unlikely, should also be kept open. The study of eclipsing CVs (during quiescence), preferably with high spectral resolution instruments, can shed light on these issues.

c) Temperatures and Luminosities

The temperatures and luminosities found are generally consistent with expectations for accretion driven, rather than coronal x-ray emission, bearing in mind that the range of accretion rates and white dwarf masses is fairly broad. As noted in §III, systems with high accretion rates ($\dot{M} \gg 10^{16}$ g s^{-1}) also show substantial x-ray luminosities. At such high accretion rates the boundary layer is expected to become optically thick and radiate a black body spectrum with a temperature around 10^5K (Pringle 1977). PR, however, have pointed out that a density gradient will certainly exist in a real boundary layer, which implies that there will be low density regions which will remain optically thin, even at high accretion rates, and hence radiate hard x-rays. At accretion rates $\sim 10^{18}$ g s^{-1} the boundary layer luminosity is $\sim 10^{35}$ erg s^{-1} and most of it emerges in the EUV/soft x-ray band, with only a very small fraction appearing as hard x-rays (Patterson and Raymond 1985*b*).

The variability in the spectral parameters of V603 Aql and SU UMa could be due to changes in the mass accretion rate. V603 Aql is believed to have a very high accretion rate ($\dot{M} \approx 10^{18}$ g s^{-1}; PR), which means that most of the boundary layer is optically thick. If the temperature increase is a result of a drop in the accretion rate (see equation (4)) then this would imply an increase in the volume of the boundary layer that is optically thin and hence an increase in the hard x-ray luminosity. SU UMa, on the other hand, is believed to have a "sub-critical" accretion rate: $\dot{M} \approx 2 \times 10^{15}$ g s^{-1} (PR), which means that the boundary layer is a hot, optically thin plasma. According to equation (4) an increase in accretion rate would produce the observed temperature drop. Such an increase in accretion rate would have a twofold effect on the x-ray emitting plasma: it would increase its total luminosity but at the same time it would make parts of it optically thick and thus suppress the volume that can emit hard x-rays. It is possible that the competition between these two effects will leave the hard x-ray luminosity unaffected.

d) High Column Densities

The column densities found in most sources are consistent with the absorption being interstellar, but, as noted in §III, a few sources show unusually high absorption in their spectra. Let us first concentrate on GK Per, which is a DQ Her system, in which the x-rays are probably produced in the hot, post - shock region at the base of the accretion column. The distance of the shock front from the surface of the white dwarf is very small, and so the x-rays have to travel a large distance in the relatively cool accretion column before they reach the observer (Fabian, Pringle and Rees 1976; King and Shaviv 1984b). The estimate of the column density of absorbing material in the accretion column, given by Fabian, Pringle and Rees (1976), can be combined with their estimate of the fraction of the white dwarf surface on which accretion occurs, and with the approximate white dwarf mass - radius relation (equation (2)) to obtain:

$$N_H \approx 4.3 \times 10^{22} \, \dot{M}_{17} \, M_{0.7}^{-1.34} \, B_5^{-0.29} \text{ cm}^{-2} \tag{6}$$

where B_5 is the magnetic field strength in units of 10^5G and $\dot{M}_{17}$ is the accretion rate in units of 10^{17} g s^{-1}, which is roughly the value quoted for GK Per by PR. This can account for the large absorption observed in the spectrum of GK Per as being due to cool material in the accretion column. The other DQ Her stars in our collection do not show highly absorbed spectra simply because the accretion rates are very low compared to GK Per. We note that the ability of the cool material in the accretion column to absorb x-rays places an upper limit on its temperature of $\sim 10^5$K (Krolik and Kallman 1984).

Now we focus our attention on the three (presumed) disk accretors with highly absorbed spectra: HT Cas, BV Cen and EM Cyg (we note that the column density in these three sources is so high it is virtually impossible to constrain the temperature; see the confidence contours for HT Cas, BV Cen and EM Cyg in Figure 1a). If we assume that the x-rays from the boundary layer have to traverse, say, a tenuous atmosphere around the accretion disk and boundary layer, then the geometry would be similar to that studied by Kallman and McCray (1982) (x-ray source embedded in a spherical gas cloud) and we can use their results to assess the plausibility of this scenario. We can compute the value of their ionization parameter, defined as $\xi \equiv L/n_H R^2 = L/N_H R$, where n_H is the density of the absorbing gas, N_H is the column density along the line of sight, and R is the radial distance from the x-ray source at the center of the gas cloud, which in our case ranges from the white dwarf radius [that can be determined from equation (2)] to the Roche lobe radius of the primary [that can be found from the masses of the two components given by Patterson (1984)]. We find that for HT Cas: $0.25 > \log \xi > -0.3$, for BV Cen: $1.1 > \log \xi > -1.1$ and for EM Cyg: $1.2 > \log \xi > -0.6$. This means that throughout most of the cloud almost all atoms will retain their electrons and the gas will act as an effective absorber, thus making the scenario self - consistent. The density implied by the observed column densities is $n_H \sim 10^{12}$cm^{-1}. There remains, however, the question of how such a cool atmosphere (with a temperature comparable to that of the disk) that fills the Roche lobe is produced and sustained, and since there is no mechanism known to give rise to such an effect we consider this scenario implausible.

Since these three systems are thought to have high inclinations (Córdova and Mason 1983) we can alternatively assume that the absorption occurs in the outer parts of the accretion disk. This is *a posteriori* and not a very "safe" assumption because other highly inclined systems (such as U Gem and WZ Sge) show very low absorption. The geometry in this case is similar to that of Krolik and Kallman (1984) (a thin slab of absorbing material illuminated by a distant x-ray source) and so we can use their results to constrain the properties of the material responsible for the absorption. Their Figure 6 implies an upper limit to the temperature of the absorbing medium of 2.5×10^5K and an upper limit on the ionization parameter of 30. The ionization parameter is defined for this geometry as: $\Xi = L/4\pi r^2 c\, n_H kT$ where n_H is the number density of hydrogen atoms in the absorbing slab and $L/4\pi r^2 c$ is the incident flux. If we define s to be the thickness of the absorber then we may express the ionization parameter as: $\Xi = Ls/4\pi r^2 c N_H kT$, and we can use the upper limits on Ξ and T together with the observed values of L and N_H to constrain the quantity s/r^2. We find that for HT Cas: $s/r^2 < 1.7 \times 10^{-7}$ cm^{-1}, for BV Cen: $s/r^2 < 2.5 \times 10^{-7}$ cm^{-1} and for EM Cyg: $s/r^2 < 6.5 \times 10^{-9}$ cm^{-1}. Following Pringle (1981) and Bath and Pringle (1985) we estimate that at radii comparable to the Roche lobe radius the thickness of the disk can be as large as 10^8 cm and the temperature around 10^4K. So if the x-rays have to travel through a distance $s \sim 10^8$ cm in the outer parts of the disk then the values of s and r comply with the constrain on s/r^2 and are quite reasonable in view of the temperature of the absorber. The density of the absorbing medium implied by this scenario is: $n_H \sim 10^{14}$cm^{-3}.

V. SUMMARY AND CONCLUSIONS

(1) We have determined spectral parameters of CVs observed with the *Einstein* IPC by fitting an optically thin thermal bremsstrahlung model to the observed spectra. The temperatures found are generally of order a few keV, but in some cases the IPC is probably detecting only the low energy end of a very hard spectrum (temperature substantially in excess of 10 keV). X-ray luminosities are in the range $10^{30} - 10^{32}$ erg s^{-1}. In some sources the spectral parameters seem to be highly variable and this could be attributed to episodic variations in the accretion rate.

(2) The thermal bremsstrahlung model seems to provide a good description of observed spectra which supports the idea that the x-rays originate in a hot, optically thin disk/star boundary layer or, in the case of DQ Her stars, a post shock region at the base of the accretion column. The results (temperatures and luminosities) generally agree with predictions based on the models. Systems with high accretion rates also show appreciable luminosities in the *Einstein* IPC bandpass, which indicates that even in this regime there are low density regions in the boundary layer which remain optically thin and are able to radiate hard x-rays.

(3) The x-ray luminosities that we find are substantially greater than those due to coronal x-ray emission from late type stars (although temperatures can be

comparable) and they show no obvious correlation with the properties of CV secondaries. This implies that the bulk of the x-ray emission is due to accretion with only a very small contribution from the corona of the companion star.

(4) With only very few exceptions, the absorption seen in the x-ray spectra of stars in our collection can be attributed to interstellar material. The unusually high column densities that we see in some systems suggests that the absorption occurs in cool material in the vicinity of the source itself. In GK Per, which is a DQ Her system, the absorption is probably due to cool material in the accretion column. The cause of the high absorption in some disk accretors is unclear, but absorption in the outer edge of the accretion disk seems plausible.Absorption in a cool atmosphere that fills the Roche lobe of the primary is possible but appears rather implausible in the absence of a mechanism for producing such an atmosphere.

What is much needed at this point is observations in the soft x-ray band (0.1 - 1 keV) at a higher sensitivity and spectral resolution than that afforded by the *Einstein* IPC. As shown by Patterson and Raymond (1985*b*) the flux that one would expect to see in this bandpass is only about 10^{-12} erg cm^2 s^{-1}, with the result that soft x-rays have only been detected from U Gem and SS Cyg in outburst. The soft x-ray band can provide valuable clues about the emission mechanisms and hence the structure and physical conditions of the boundary layer, and yet it remains unexplored.

Since the spectra of CVs are relatively hard – some are described by temperatures in excess of 10 keV – the IPC can provide very little information about their high energy end. Observations in a broad band up to 10 - 20 keV can thus be very useful. *Einstein* observations of CVs suffer from the additional drawback of being very short (of order a few thousand seconds). Because these stars are relatively weak x-ray sources only very few photons were collected, in some cases so few that a spectral analysis is barely possible.

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TABLE 1
DETAILS OF OBSERVATIONS

Source	Subclass [a]	Distance [b] (pc)	Observation Date	Sequence No.	Exposure Time (s)	Counts [c]
RX And	dN	200	1980 Jan 11	2255	2170	476.1 ± 23.3
V603 Aql	cN	380	1979 Oct 21	1749	1801	423.5 ± 21.9
			1981 Mar 9	10113	11229	7800.3 ± 92.3
V794 Aql	Nl	200	1980 Apr 13	7909	2323	387.9 ± 21.2
AE Aqr	Nl/DQ	80	1979 Apr 27	3247	4585	1147.8 ± 35.9
			1980 May 13	8415	16157	4243.5 ± 68.6
			1981 Apr 25	10624	5556	1439.6 ± 40.6
TT Ari	Nl	125	1979 Jul 23	3187	1597	693.0 ± 27.1
			1980 Jul 19	7614	24019	13747.6 ±123.4
HT Cas	dN	190	1980 Jan 23	4919	2158	128.7 ± 13.6
BV Cen	dN	300	1980 Jan 24	4924	1349	116.7 ± 12.2
V436 Cen	dN	75	1980 Jan 9	4923	1658	340.1 ± 20.0
WW Cet	dN	130	1979 Jan 21	5951	1720	435.5 ± 22.2
HL CMa	dN	80	1980 Mar 23	6962	35430	1621.6 ± 43.1
			1980 Mar 22	6963	6997	1109.5 ± 35.7
			1980 Oct 4	10183	6942	4446.5 ± 69.6
			1980 Oct 4	10184	8568	3937.4 ± 65.8
YZ Cnc	dN	130	1979 Apr 8	3354	2908	107.3 ± 14.3
TV Col	DQ	160	1979 Sep 10	4497	2048	438.2 ± 22.2
			1979 Sep 11	4498	3769	740.0 ± 30.2
GP Com	Nl	75	1980 Jul 8	7878	1760	365.7 ± 20.6
EM Cyg	dN	350	1979 Oct 6	2275	2048	172.4 ± 16.6
AB Dra	dN	200	1979 Oct 23	4928	2140	200.5 ± 16.5
YY Dra	dN	110	1980 Apr 20	6244	1573	253.8 ± 17.0
U Gem	dN	75	1979 Apr 29	948	1679	161.2 ± 13.7
			1979 Apr 29	3179	4137	358.4 ± 20.4
EX Hya	dN/DQ	125	1979 Jan 13	2267	1679	3004.8 ± 55.7
			1980 Jul 24	2268	1038	2177.1 ± 47.4
			1980 Jul 28	7714	23359	53563.7 ±234.6
VW Hyi	dN	100	1979 Feb 26	3352	3245	126.5 ± 13.2
WX Hyi	dN	120	1979 Nov 21	4920	1460	107.7 ± 12.8
MV Lyr	Nl	320	1979 Apr 29	2273	1809	194.5 ± 15.4
			1979 Oct 6	2274	2416	82.1 ± 10.9
			1980 Apr 29	4622	8645	272.8 ± 21.3
RU Peg	dN	250	1980 Oct 21	2279	1802	1494.4 ± 40.0
GK Per	cN/DQ	500	1979 Aug 26	1757	1679	200.2 ± 15.4
			1979 Feb 25	3188	1881	462.1 ± 23.0
			1980 Feb 14	5174	21088	3188.7 ± 61.0
AO Psc	DQ	250	1979 May 25	3655	573	129.3 ± 12.2
CP Pup	cN	700	1979 Nov 24	1752	2647	107.7 ± 12.8
RW Sex	Nl	150	1979 Nov 2	3186	2055	124.4 ± 12.8
V Sge	Nl	2700	1979 May 2	3507	9061	157.7 ± 18.9
WZ Sge	dN	80	1979 Apr 30	2277	3348	512.6 ± 25.4
			1980 Apr 21	3508	3647	466.4 ± 24.1
			1980 May 7	7876	9765	927.2 ± 35.0
V3885 Sgr	Nl	140	1979 Mar 29	3185	2432	185.7 ± 16.9
SU UMa	dN	140	1979 Oct 4	3355	1348	623.5 ± 26.1
			1980 Sep 26	8018	9753	4016.9 ± 66.4
			1980 Apr 29	8357	6267	5556.9 ± 77.5
TW Vir	dN	140	1980 Oct 12	7618	3809	188.8 ± 15.5
Nova Vul 1979	cN		1981 Apr 16	8698	6132	105.8 ± 13.8

Notes on Table 1

[a] Subclasses according to: Córdova and Mason 1984; Córdova, Jensen and Nugent 1981; Córdova and Mason 1983.
cN = Classical Nova, dN = Dwarf Nova, Nl = Nova-Like Variable, DQ = DQ Her star

[b] Distances taken from Patterson 1984.

[c] After background subtraction.

TABLE 2

BEST FIT SPECTRAL PARAMETERS AND ESTIMATED LUMINOSITIES

Source	Sequence Number	χ^2_{min} [a]	kT (keV)	N_H (10^{21} cm^{-2})	Observed [b,c] F_x (0.1 - 3.5 keV) (10^{-11} erg cm^{-2} s^{-1})	Unabsorbed [d] F_x (0.1 - 3.5 keV) (10^{-11} erg cm^{-2} s^{-1})	Observed [b,e] L_x (0.1 - 3.5 keV) (10^{31} erg s^{-1})
RX And	2255	0.60	$2.4^{+18.1}_{-1.7}$	$1.0^{+3.4}_{-0.8}$	$0.64^{+0.05}_{-0.09}$	0.10	$3.0^{+0.3}_{-0.4}$
V603 Aql	1749	1.70	$2.9^{+\infty}_{-2.0}$	$1.0^{+3.4}_{-0.7}$	$0.75^{+0.07}_{-0.12}$	1.13	$13.0^{+1.2}_{-2.1}$
	10113	1.67	$26^{+\infty}_{-19}$	$1.2^{+0.7}_{-0.2}$	$2.19^{+0.03}_{-0.09}$	2.95	$37.7^{+0.5}_{-1.5}$
V794 Aql	7909	1.07	$1.2^{+\infty}_{-0.8}$	$5.9^{+12.1}_{-5.0}$	$0.47^{+0.09}_{-0.07}$	1.89	$2.3^{+0.4}_{-0.3}$
AE Aqr	3247	0.94	$1.00^{+0.55}_{-0.31}$	$0.19^{+0.15}_{-0.13}$	$0.59^{+0.03}_{-0.03}$	0.81	$0.45^{+0.02}_{-0.03}$
	8415	0.91	$1.41^{+0.40}_{-0.28}$	$0.16^{+0.08}_{-0.07}$	$0.68^{+0.02}_{-0.02}$	0.85	$0.52^{+0.01}_{-0.01}$
	10624	1.14	$0.83^{+0.34}_{-0.22}$	$0.33^{+0.22}_{-0.16}$	$0.67^{+0.03}_{-0.04}$	1.08	$0.52^{+0.03}_{-0.03}$
TT Ari	3187	1.19	$2.0^{+18.0}_{-1.3}$	$2.0^{+4.0}_{-1.5}$	$1.3^{+0.1}_{-0.2}$	2.5	$2.4^{+0.2}_{-0.3}$
	7614	1.43	$3.49^{+2.49}_{-0.93}$	$3.1^{+0.7}_{-0.8}$	$1.74^{+0.06}_{-0.05}$	3.36	$3.3^{+0.1}_{-0.1}$
HT Cas	4919	0.76	$0.2^{+\infty}_{-\infty}$	$24^{+\infty}_{-23}$	$0.17^{+0.08}_{-0.02}$	...	$0.7^{+0.3}_{-0.1}$
BV Cen	4924	1.06	$0.7^{+\infty}_{-\infty}$	17^{+82}_{-15}	$0.4^{+0.2}_{-0.2}$	6.0	3^{+2}_{-1}
V436 Cen	4923	1.37	$4.9^{+\infty}_{-4.0}$	$0.4^{+2.8}_{-0.3}$	$0.66^{+0.05}_{-0.10}$	0.80	$0.44^{+0.03}_{-0.09}$
WW Cet	5951	0.74	$14.0^{+\infty}_{-11.9}$	$0.35^{+0.95}_{-0.19}$	$0.70^{+0.05}_{-0.07}$	0.95	$1.62^{+0.09}_{-0.15}$
HL CMa	6962	0.54	$1.6^{+4.3}_{-0.8}$	$3.5^{+3.2}_{-2.1}$	$1.6^{+0.2}_{-0.1}$	4.2	$1.2^{+0.1}_{-0.1}$
	6963	0.49	$0.72^{+0.86}_{-0.35}$	$7.8^{+8.3}_{-4.0}$	$1.11^{+0.09}_{-0.11}$	8.99	$0.85^{+0.07}_{-0.09}$
	10183	3.80	$2.1^{+1.5}_{-0.7}$	$3.4^{+1.4}_{-1.1}$	$2.02^{+0.09}_{-0.12}$	4.61	$1.55^{+0.07}_{-0.09}$
	10184	1.63	$2.2^{+1.9}_{-0.8}$	$3.1^{+1.6}_{-1.2}$	$1.55^{+0.05}_{-0.06}$	3.35	$1.19^{+0.04}_{-0.05}$
YZ Cnc	3354	1.44	$1.2^{+\infty}_{-\infty}$	2^{+23}_{-2}	$0.12^{+0.03}_{-0.03}$	0.29	$0.24^{+0.05}_{-0.06}$
TV Col	4497	3.16	> 3.5	$4.1^{+2.8}_{-2.6}$	$0.89^{+0.05}_{-0.07}$	1.55	$2.7^{+0.2}_{-0.2}$
	4498	4.31	> 5.2	$8.4^{+6.6}_{-2.5}$	$0.65^{+0.04}_{-0.04}$	1.41	$2.0^{+0.1}_{-0.1}$
GP Com	7878	1.12	> 2.7	< 0.28	$0.59^{+0.04}_{-0.05}$	0.61	$0.40^{+0.03}_{-0.04}$
EM Cyg	2275	1.47	$2^{+\infty}_{-\infty}$	12^{+87}_{-9}	$0.30^{+0.07}_{-0.10}$	1.21	4^{+1}_{-2}
AB Dra	4928	1.21	> 0.49	4^{+31}_{-3}	$0.32^{+0.05}_{-0.07}$	0.57	$1.6^{+0.2}_{-0.3}$
YY Dra	6244	3.93	> 4.4	< 0.36	$0.90^{+0.09}_{-0.10}$	0.97	$1.3^{+0.1}_{-0.1}$

TABLE 2 *Continued*

Source	Sequence Number	χ^2_{min} [a]	kT (keV)	N_H (10^{21} cm^{-2})	Observed [b,c] F_x (0.1 - 3.5 keV) (10^{-11} erg cm^{-2} s^{-1})	Unabsorbed [d] F_x (0.1 - 3.5 keV) (10^{-11} erg cm^{-2} s^{-1})	Observed [b,e] L_x (0.1 - 3.5 keV) (10^{31} erg s^{-1})
U Gem	948	1.90	$1.7^{+17.1}_{-1.2}$	$0.2^{+2.9}_{-\infty}$	$0.27^{+0.03}_{-0.04}$	0.33	$0.18^{+0.02}_{-0.03}$
	3179	1.03	$2.0^{+8.9}_{-1.4}$	$0.35^{+2.75}_{-0.32}$	$0.26^{+0.02}_{-0.05}$	0.35	$0.18^{+0.01}_{-0.03}$
EX Hya	2267	3.70	$9.5^{+\infty}_{-6.1}$	$0.09^{+0.07}_{-0.03}$	$6.5^{+0.3}_{-0.5}$	7.0	$12.1^{+0.6}_{-0.9}$
	2268	1.04	> 12	$0.25^{+0.15}_{-0.07}$	$8.9^{+0.3}_{-0.2}$	10.2	$16.7^{+0.5}_{-0.4}$
	7714	9.33	$3.4^{+0.4}_{-0.3}$	$0.26^{+0.02}_{-0.03}$	$7.08^{+0.04}_{-0.04}$	8.62	$13.2^{+0.1}_{-0.1}$
VW Hyi	3352	2.23	> 0.74	< 0.81	$0.14^{+0.02}_{-0.04}$	0.17	$0.20^{+0.03}_{-0.05}$
WX Hyi	4920	1.02	$2^{+\infty}_{-\infty}$	$2^{+35}_{-1.9}$	$0.18^{+0.03}_{-0.06}$	0.34	$0.30^{+0.06}_{-0.10}$
MV Lyr	2273	0.98	$4.9^{+\infty}_{-4.5}$	$2.9^{+22}_{-2.5}$	$0.34^{+0.03}_{-0.09}$	0.61	$4.2^{+0.4}_{-1.0}$
	4622	2.76	> 0.22	$1.4^{+38}_{-1.2}$	$0.12^{+0.01}_{-0.04}$	0.16	$1.4^{+0.1}_{-0.5}$
RU Peg	2279	1.73	$2.9^{+5.3}_{-1.5}$	$1.3^{+1.5}_{-0.8}$	$2.4^{+0.1}_{-0.1}$	3.9	$18.2^{+0.7}_{-1.1}$
GK Per	1757	3.10	> 0.39	$8.4^{+42.6}_{-5.7}$	$0.46^{+0.05}_{-0.10}$	0.99	14^{+1}_{-3}
	3188	0.43	$2.4^{+\infty}_{-1.9}$	$8.4^{+17.6}_{-5.2}$	$0.78^{+0.08}_{-0.11}$	2.45	23^{+2}_{-3}
	5174	0.97	$2.9^{+\infty}_{-1.8}$	$12.8^{+9.2}_{-5.1}$	$0.57^{+0.04}_{-0.05}$	2.00	17^{+1}_{-1}
AO Psc	3655	1.57	$4.9^{+\infty}_{-4.5}$	1^{+15}_{-1}	$0.8^{+0.1}_{-0.2}$	1.1	6^{+1}_{-2}
CP Pup	1752	2.50	> 0.57	< 7.6	$0.14^{+0.02}_{-0.04}$	0.15	8^{+1}_{-3}
RW Sex	3186	0.87	> 0.52	$0.35^{+8.45}_{-0.28}$	$0.23^{+0.02}_{-0.07}$	0.27	$0.6^{+0.1}_{-0.2}$
V Sge	3507	0.60	< 1.5	< 0.8	$0.04^{+0.02}_{-0.01}$	0.04	30^{+20}_{-10}
WZ Sge	2277	1.84	$5.8^{+\infty}_{-4.8}$	$0.7^{+4.1}_{-0.5}$	$0.46^{+0.03}_{-0.08}$	0.62	$0.36^{+0.02}_{-0.06}$
	3508	0.95	$4.1^{+\infty}_{-3.0}$	$0.5^{+2.1}_{-0.4}$	$0.39^{+3}_{-0.06}$	0.51	$0.30^{+0.02}_{-0.04}$
	7876	2.20	$2.9^{+17.2}_{-1.9}$	$1.0^{+3.2}_{-0.7}$	$0.30^{+0.03}_{-0.04}$	0.46	$0.23^{+0.02}_{-0.03}$
V3885 Sgr	3185	1.12	$1.2^{+\infty}_{-0.9}$	$0.2^{+1.9}_{-\infty}$	$0.16^{+0.03}_{-0.03}$	0.22	$0.38^{+0.07}_{-0.06}$
SU UMa	3355	1.19	$11.8^{+\infty}_{-9.2}$	$0.08^{+0.24}_{-0.07}$	$1.3^{+0.1}_{-0.1}$	1.4	$3.1^{+0.2}_{-0.3}$
	8018	2.13	$2.11^{+0.81}_{-0.50}$	$0.22^{+0.12}_{-0.08}$	$1.26^{+0.05}_{-0.06}$	1.57	$2.9^{+0.1}_{-0.1}$
	8357	3.16	$1.49^{+0.29}_{-0.28}$	$0.32^{+0.12}_{-0.07}$	$1.41^{+0.02}_{-0.02}$	1.94	$3.30^{+0.05}_{-0.05}$
TW Vir	7618	1.95	$6.9^{+\infty}_{-6.7}$	$0.5^{+24.5}_{-0.4}$	$0.16^{+0.02}_{-0.06}$	0.20	$0.38^{+0.04}_{-0.13}$
N Vul1979	8698	2.05	$3.4^{+\infty}_{-\infty}$	$0.14^{+0.03}_{-0.05}$	0.15		

Notes on Table 2

[a] Minimum χ^2 per degree of freedom.

[b] Observed values, not corrected for absorption.

[c] Error bars include uncertainties due to counting statistics and the fitting process but not instrument calibration.

[d] Best fit value of the flux corrected for absorption using the best fit value of the column density.

[e] Error bars include uncertainties in the flux but not in the distance.

TABLE 3

CV Companion Star Parameters

Source	Spectral Type [a]	Rotation Period [a,b] (days)	Radius (10^5 km)	Equatorial Rotational Velocity ($km\,s^{-1}$)
RX And	> K9	0.211	< 4.54 [d]	< 156
V603 Aql	> G8	0.145	< 6.11 [d]	< 307
AE Aqr	K5	0.412	7.12 [c]	126
BV Cen	G5-8	0.61	9.67 [c]	115
V436 Cen	> M4	0.062	1.46 [c]	170
WW Cet	> M3	0.17	< 3.14 [d]	< 134
HL CMa	> M0	0.217	4.24 [d]	143
EM Cyg	K5	0.291	5.48 [c]	137
YY Dra	M5	0.163	2.19 [d]	98
U Gem	M4.5	0.177	3.77 [c]	155
EX Hya	M2	0.068	1.89 [c]	201
MV Lyr	M5	0.134	2.19 [d]	119
RU Peg	G9	0.375	5.98 [d]	116
AO Psc	> M0	0.15	< 4.26 [d]	< 207
RW Sex	> K2	0.247	< 5.86 [d]	< 173
WZ Sge	> M5	0.057	1.45 [c]	186
V3885 Sgr	> G7	0.206	< 6.25 [d]	< 221

Notes on Table 3

[a] Drawn from Patterson (1984).

[b] Same as binary orbital period (assuming synchronous rotation).

[c] Roche lobe radius estimated using the masses of the two components (taken from Patterson 1984).

[d] Radius estimated from spectral type using information from Allen (1973).

TABLE 4

BEST FIT TEMPERATURES AND ESTIMATED LUMINOSITIES FROM RAYMOND - SMITH MODEL

Source	Sequence Number	χ^2_{min} [a]	kT (keV)	L_x (0.1 - 3.5 keV) [b] (10^{31} erg s^{-1})
RX And	2255	0.54	$3.6^{+\infty}_{-1.6}$	$3.85^{+0.32}_{-0.34}$
V603 Aql	1749	1.74	$4.3^{+\infty}_{-2.1}$	$17.3^{+1.4}_{-1.6}$
	10113	1.70	> 9.2	$52.6^{+0.9}_{-1.8}$
V794 Aql	7909	1.01	$2.6^{+\infty}_{-2.3}$	$5.1^{+0.6}_{-1.1}$
AE Aqr	3247	4.80	$1.79^{+0.78}_{-0.32}$	$0.46^{+0.01}_{-0.01}$
	8415	3.71	$2.14^{+0.23}_{-0.26}$	$0.53^{+0.01}_{-0.01}$
	10624	3.53	$1.50^{+0.32}_{-0.46}$	$0.50^{+0.02}_{-0.05}$
TT Ari	3187	1.13	$3.6^{+11.3}_{-1.6}$	$3.43^{+0.26}_{-0.33}$
	7614	1.71	$5.5^{+1.0}_{-1.3}$	$5.45^{+0.10}_{-0.22}$
BV Cen	4924	1.06	$2.1^{+\infty}_{-\infty}$	$16.3^{+4.2}_{-6.2}$
V436 Cen	4923	1.33	$3.6^{+\infty}_{-1.8}$	$0.52^{+0.05}_{-0.05}$
WW Cet	5951	0.74	$12.6^{+\infty}_{-9.8}$	$1.91^{+0.11}_{-0.23}$
HL CMa	6962	0.53	$3.4^{+3.0}_{-1.5}$	$2.11^{+0.13}_{-0.14}$
	6963	0.48	$0.6^{+2.4}_{-0.3}$	$19.9^{+4.1}_{-1.8}$
	10183	3.78	$3.6^{+1.4}_{-1.1}$	$2.72^{+0.06}_{-0.10}$
	10184	1.25	$3.5^{+1.6}_{-1.0}$	$2.05^{+0.04}_{-0.11}$
YZ Cnc	3354	1.46	$0.62^{+\infty}_{-0.47}$	$2.9^{+1.1}_{-0.6}$
TV Col	4497	3.20	> 4.6	$4.78^{+0.28}_{-0.35}$
	4498	4.40	> 4.8	$4.34^{+0.27}_{-0.22}$
GP Com	7878	1.13	> 3.1	$0.42^{+0.03}_{-0.04}$
EM Cyg	2275	1.47	$0.9^{+\infty}_{-\infty}$	90^{+29}_{-26}
AB Dra	4928	1.23	> 0.43	$3.10^{+0.36}_{-0.81}$
YY Dra	6244	4.00	> 4.7	$1.39^{+0.14}_{-0.17}$
U Gem	948	1.85	$2.6^{+12.3}_{-1.3}$	$0.18^{+0.02}_{-0.03}$
	3179	0.95	$2.6^{+7.0}_{-0.9}$	$0.19^{+0.02}_{-0.02}$
EX Hya	2267	3.38	$2.8^{+\infty}_{-1.0}$	$11.6^{+2.1}_{-1.2}$
	2268	1.19	> 8	$18.96^{+0.50}_{-0.44}$
	7714	6.54	$4.03^{+0.26}_{-0.28}$	$14.75^{+0.14}_{-0.11}$
VW Hyi	3352	2.23	$7.4^{+\infty}_{-6.1}$	$0.20^{+0.03}_{-0.04}$
WX Hyi	4920	1.00	$3.6^{+\infty}_{-\infty}$	$0.43^{+0.07}_{-0.15}$
MV Lyr	2273	1.00	$5.2^{+\infty}_{-4.9}$	$7.2^{+0.7}_{-1.8}$
	4622	2.76	> 0.87	$1.98^{+0.17}_{-0.69}$
RU Peg	2279	1.69	$4.2^{+3.9}_{-1.6}$	$24.6^{+0.8}_{-1.7}$
GK Per	1757	3.10	> 0.46	$29.8^{+3.2}_{-6.7}$
	3188	0.50	$3.6^{+\infty}_{-3.1}$	62^{+5}_{-12}
	5174	1.11	$4.3^{+\infty}_{-3.6}$	$51.3^{+2.2}_{-7.0}$
AO Psc	3655	1.57	$8.8^{+\infty}_{-8.6}$	$7.6^{+0.7}_{-2.6}$
CP Pup	1752	2.53	> 1.7	$8.8^{+1.1}_{-2.9}$
RW Sex	3186	0.89	> 1.7	$0.71^{+0.08}_{-0.22}$
V Sge	3507	1.10	$0.21^{+0.12}_{-0.06}$	35^{+22}_{-12}
WZ Sge	2277	1.85	$6.2^{+\infty}_{-3.7}$	$0.46^{+0.03}_{-0.05}$
	3508	0.98	$5.2^{+\infty}_{-3.1}$	$0.36^{+0.03}_{-0.04}$
	7876	2.20	$4.3^{+\infty}_{-2.0}$	$0.31^{+0.02}_{-0.02}$
V3885 Sgr	3185	1.26	$2.1^{+\infty}_{-1.5}$	$0.38^{+0.08}_{-0.12}$
SU UMa	3355	1.16	$8.8^{+\infty}_{-6.1}$	$3.30^{+0.14}_{-0.29}$
	8018	1.53	$2.75^{+0.78}_{-0.48}$	$3.07^{+0.06}_{-0.06}$
	8357	1.97	$2.05^{+0.29}_{-0.18}$	$3.39^{+0.06}_{-0.06}$
TW Vir	7618	1.92	$6.2^{+\infty}_{-6.0}$	$0.47^{+0.05}_{-0.15}$
Nova Vul 1979	8698	2.10	$2.55^{+\infty}_{-\infty}$	$0.32^{+0.07}_{-0.14}$

Notes on Table 4

[a] Minimum χ^2 per degree of freedom.

[b] Error bars include uncertainties due to counting statistics and the fitting process but not instrument calibration or distance determination, and are corrected for absorption using the best fit value of the column density

FIGURE CAPTIONS

FIG.1. 68% (1σ) and 90% (1.6σ) confidence contours for 51 observations of 31 CVs. The best fit (minimum χ^2) is also shown: (a) the range of parameters displayed is standard: kT: 0.2 - 20 keV, N_H : $10^{19} - 10^{23}$ cm^{-2}, and (b) the range is chosen independently for each frame to ensure clarity.

FIG.2. Plots of observed 0.1 - 3.5 keV luminosities and spectral temperatures versus radius, spectral type, orbital period, and equatorial rotational velocity of the companion star, for 18 systems from our collection. Luminosities have been corrected for absorption using the best fit value of the column density. Filled squares indicate G and K type companions while open circles indicate M type companions. The dashed line in the plot of x-ray luminosity versus radius marks the proposed saturation boundary of Fleming, Gioia and Maccacaro (1989) (see text for details).

FIG.3. Location of the CVs in our collection in the x-ray luminosity – temperature plane. Locations of different classes of stars from the sample of Schmitt *et al.* are also shown schematically (see text for details).

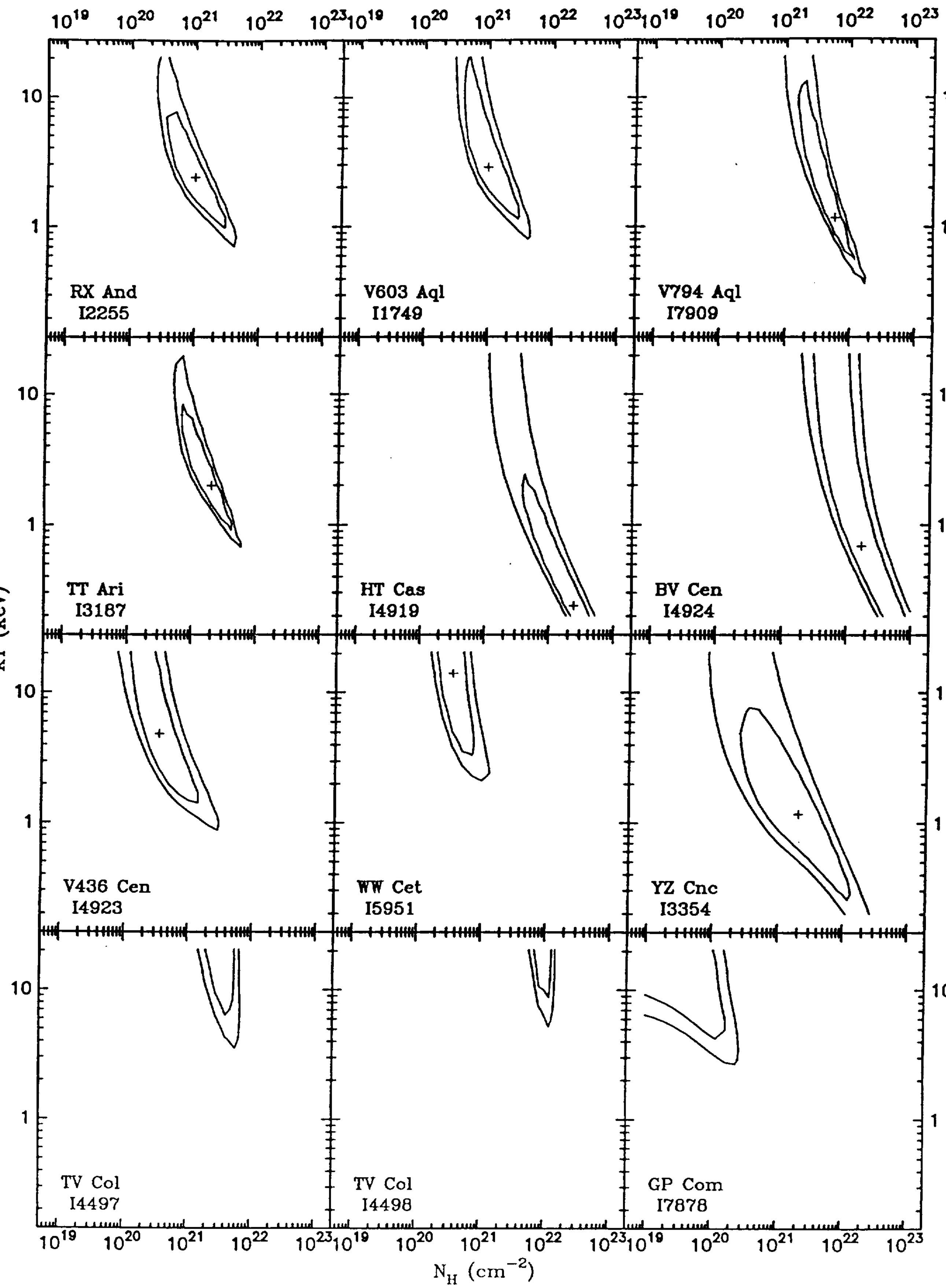

RX And
I2255
V603 Aql
I1749
V794 Aql
I7909
TT Ari
I3187
HT Cas
I4919
BV Cen
I4924
V436 Cen
I4923
WW Cet
I5951
YZ Cnc
I3354
TV Col
I4497
TV Col
I4498
GP Com
I7878
kT (keV)
N_H (cm^{-2})

Fig. 1a

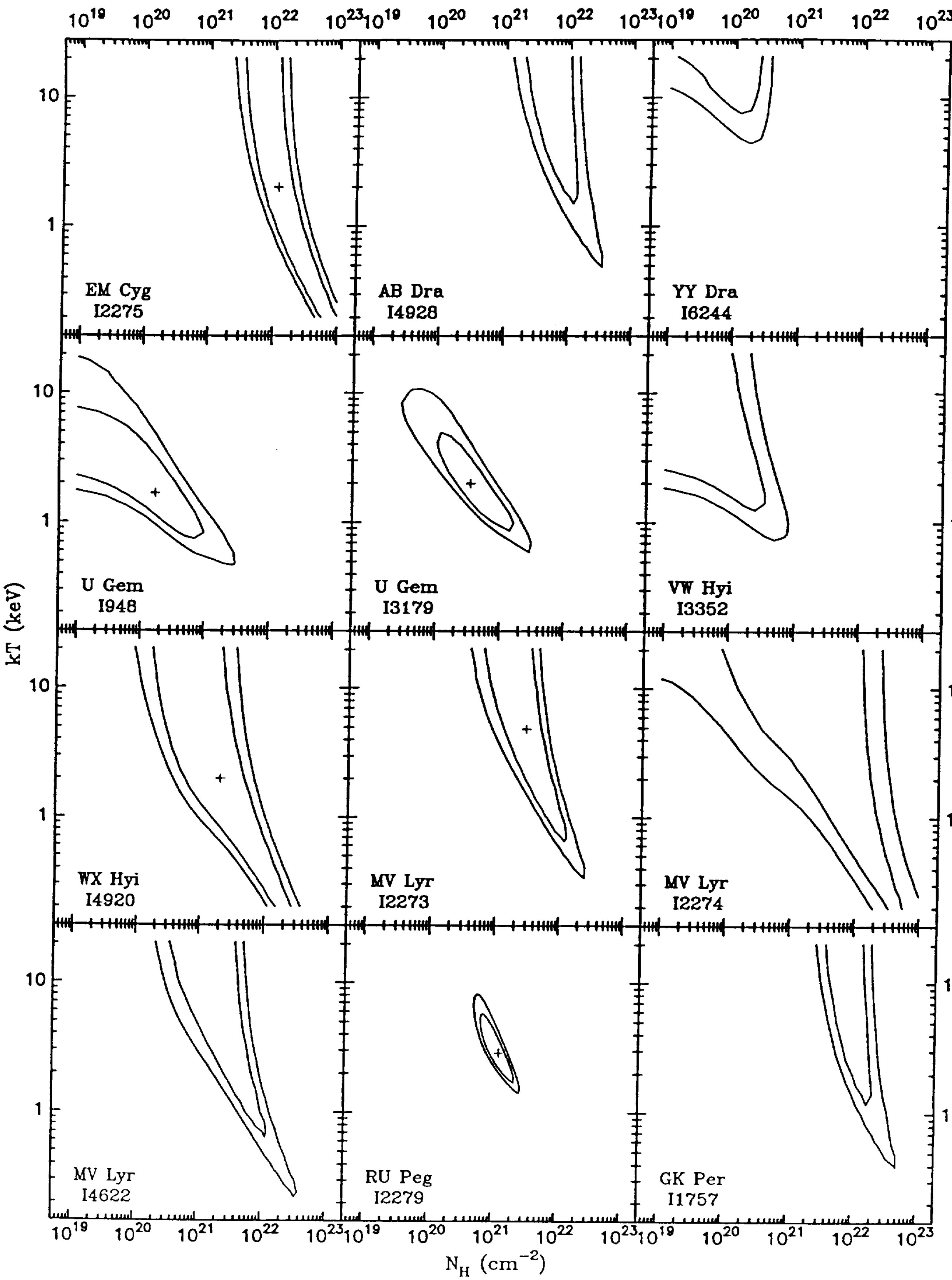


Fig. 1a (continued)

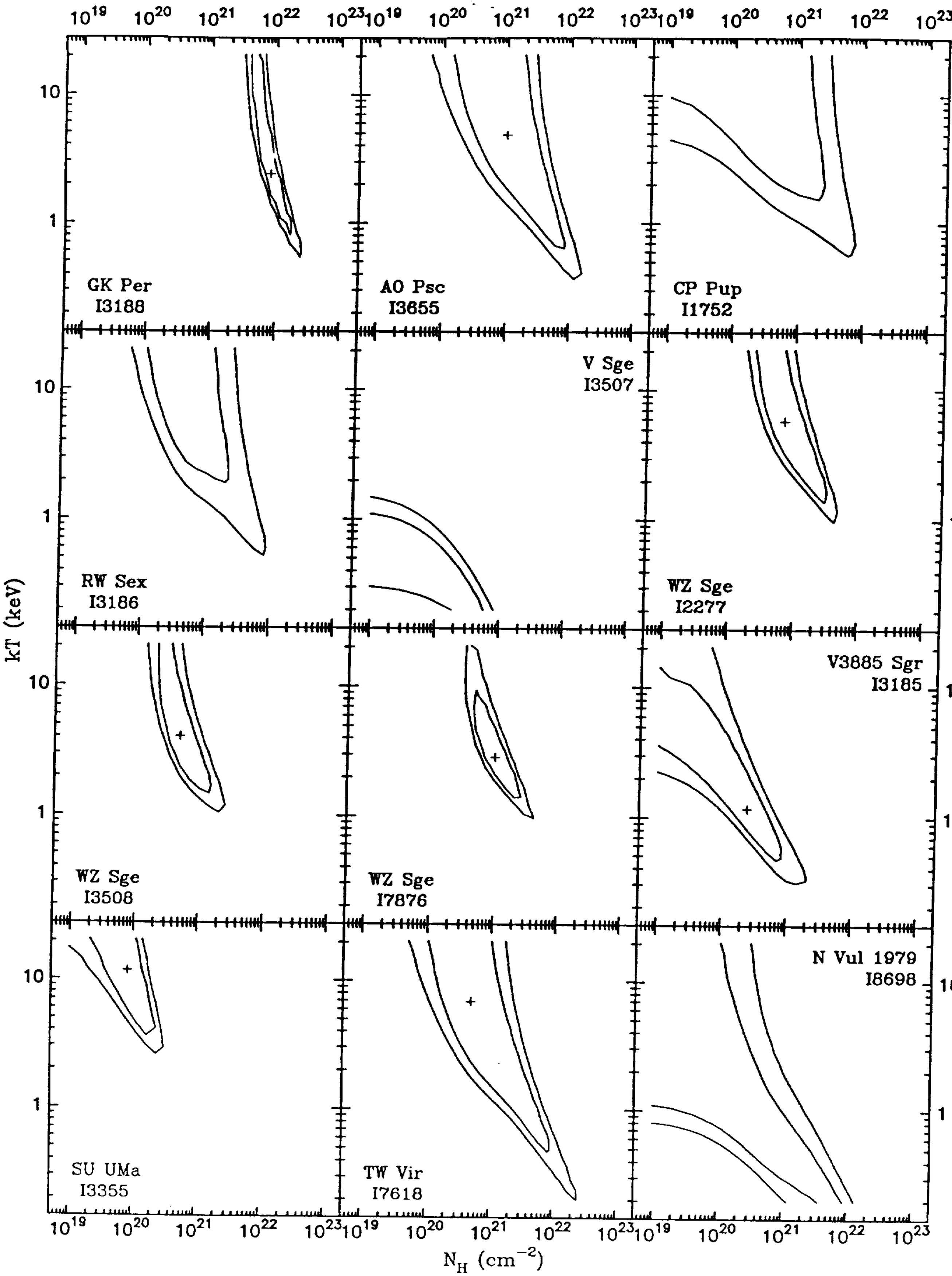


Fig. 1a (continued)

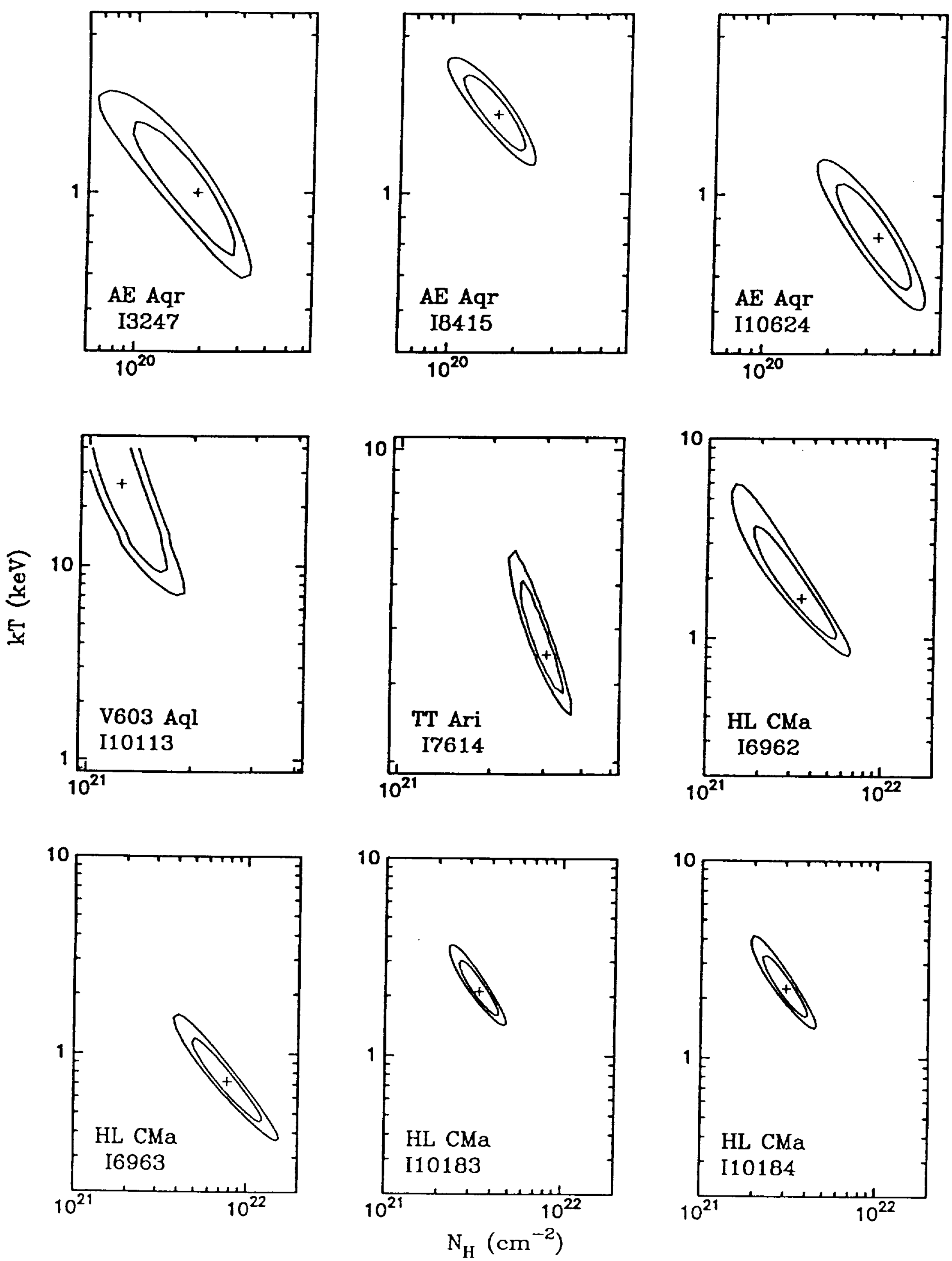

AE Aqr
I3247
AE Aqr
I8415
AE Aqr
I10624
V603 Aql
I10113
TT Ari
I7614
HL CMa
I6962
HL CMa
I6963
HL CMa
I10183
HL CMa
I10184
kT (keV)
N_H (cm^{-2})
1
10
10^{20}
10^{21}
10^{22}

Fig. 1b

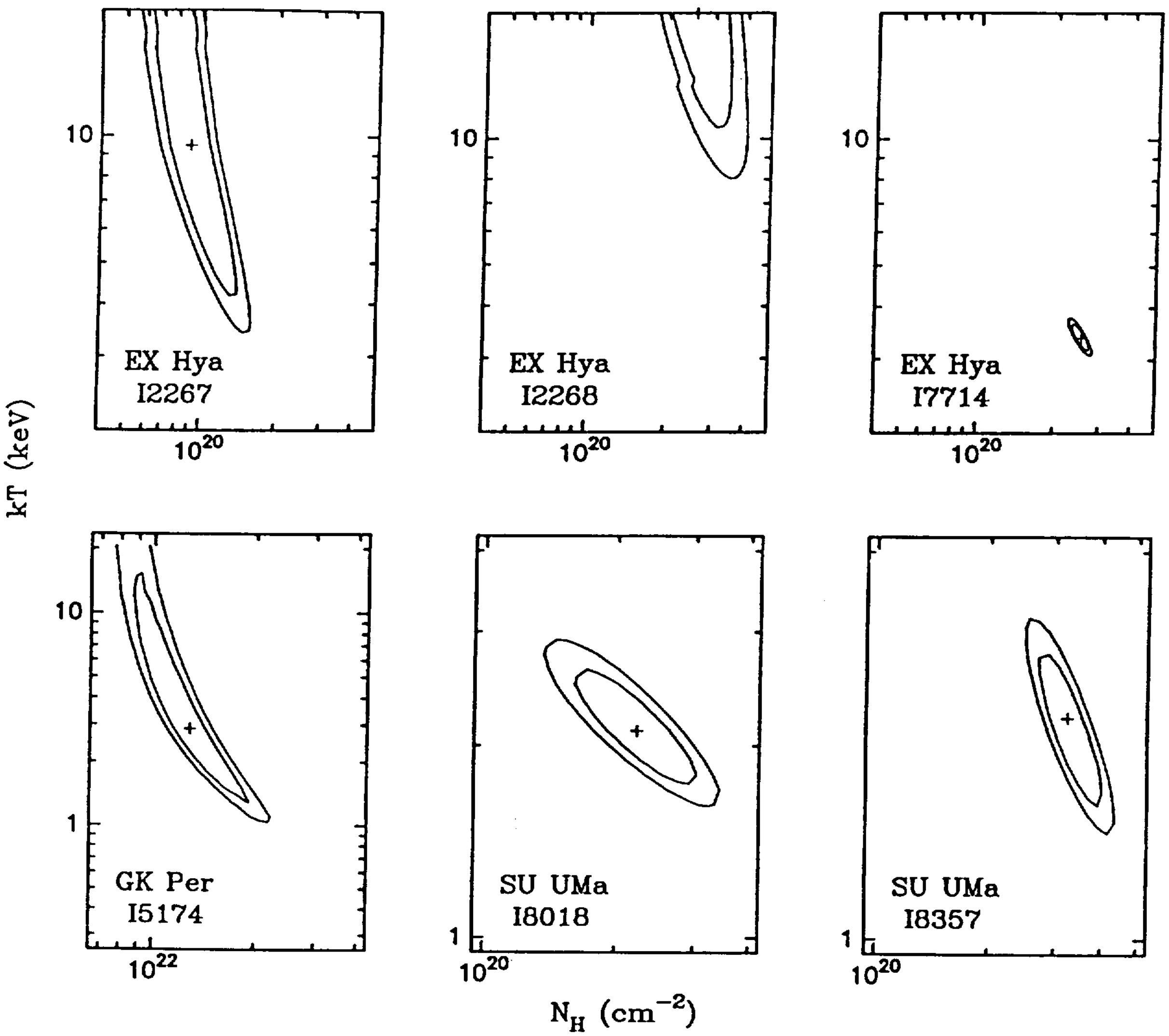
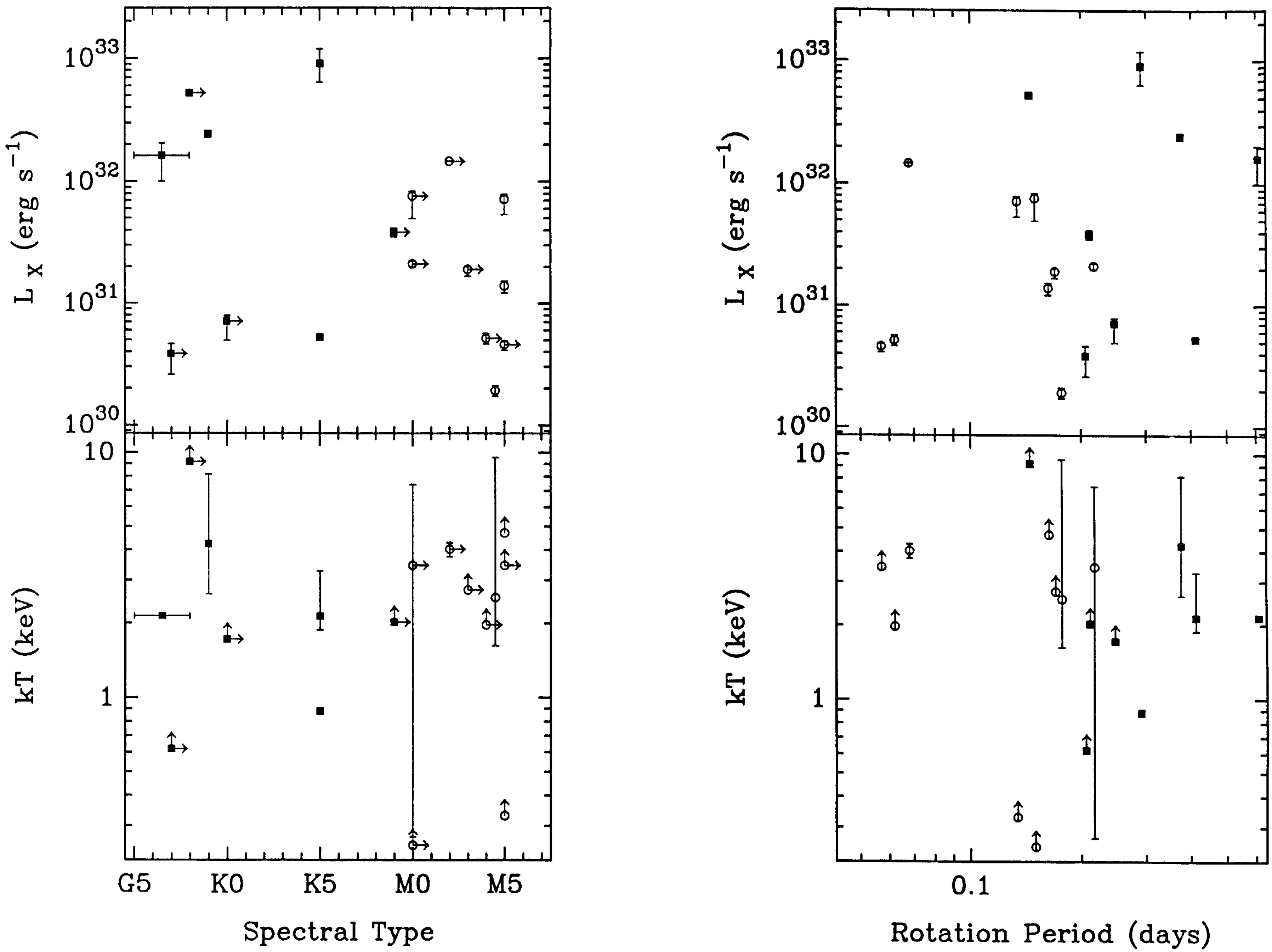


Fig. 1b (continued)



10^{33}
10^{32}
10^{31}
10^{30}
L X (erg s^{-1})
10
1
kT (keV)
G5
K0
K5
M0
M5
Spectral Type
0.1
Rotation Period (days)

Fig. 2

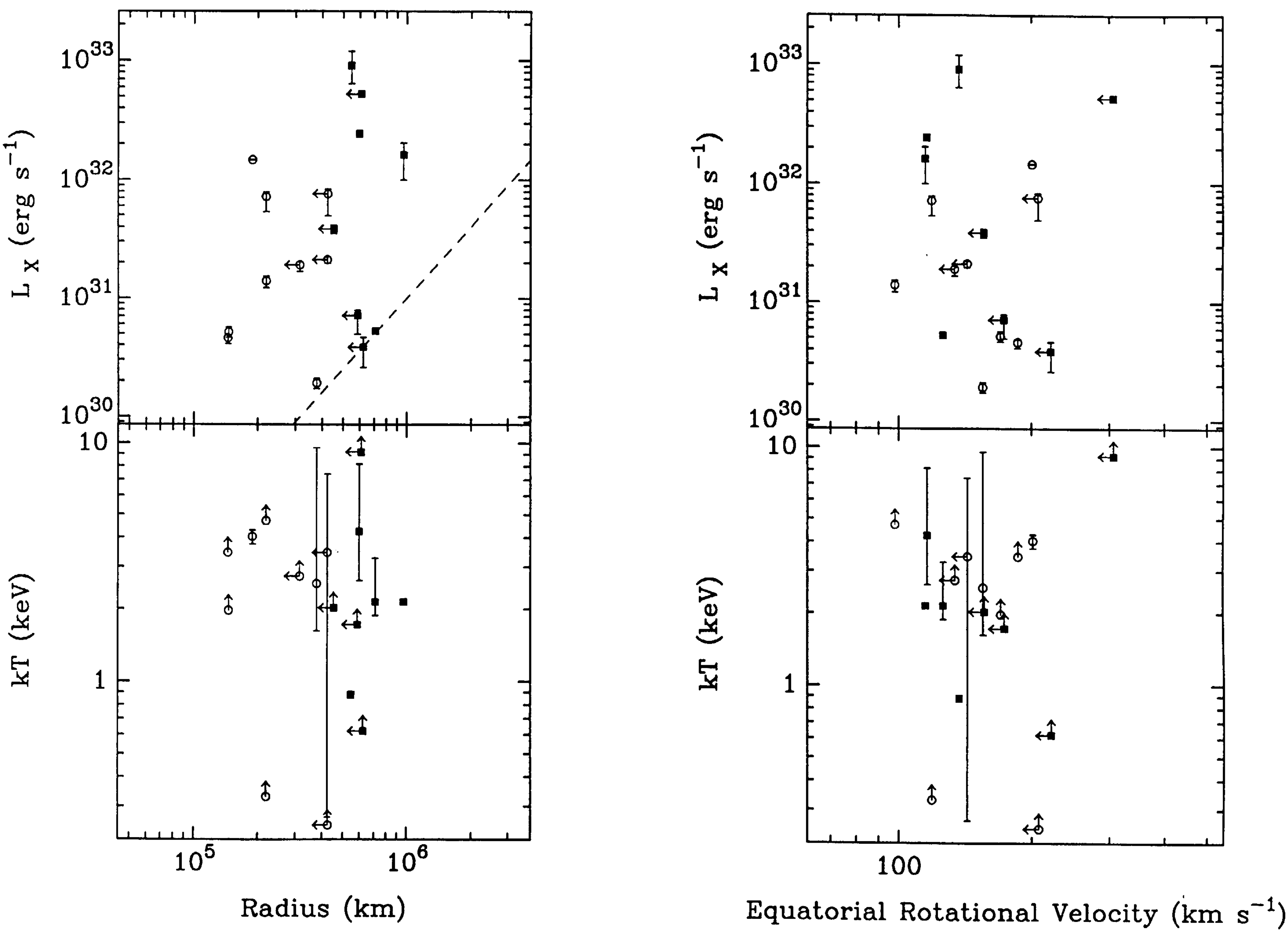
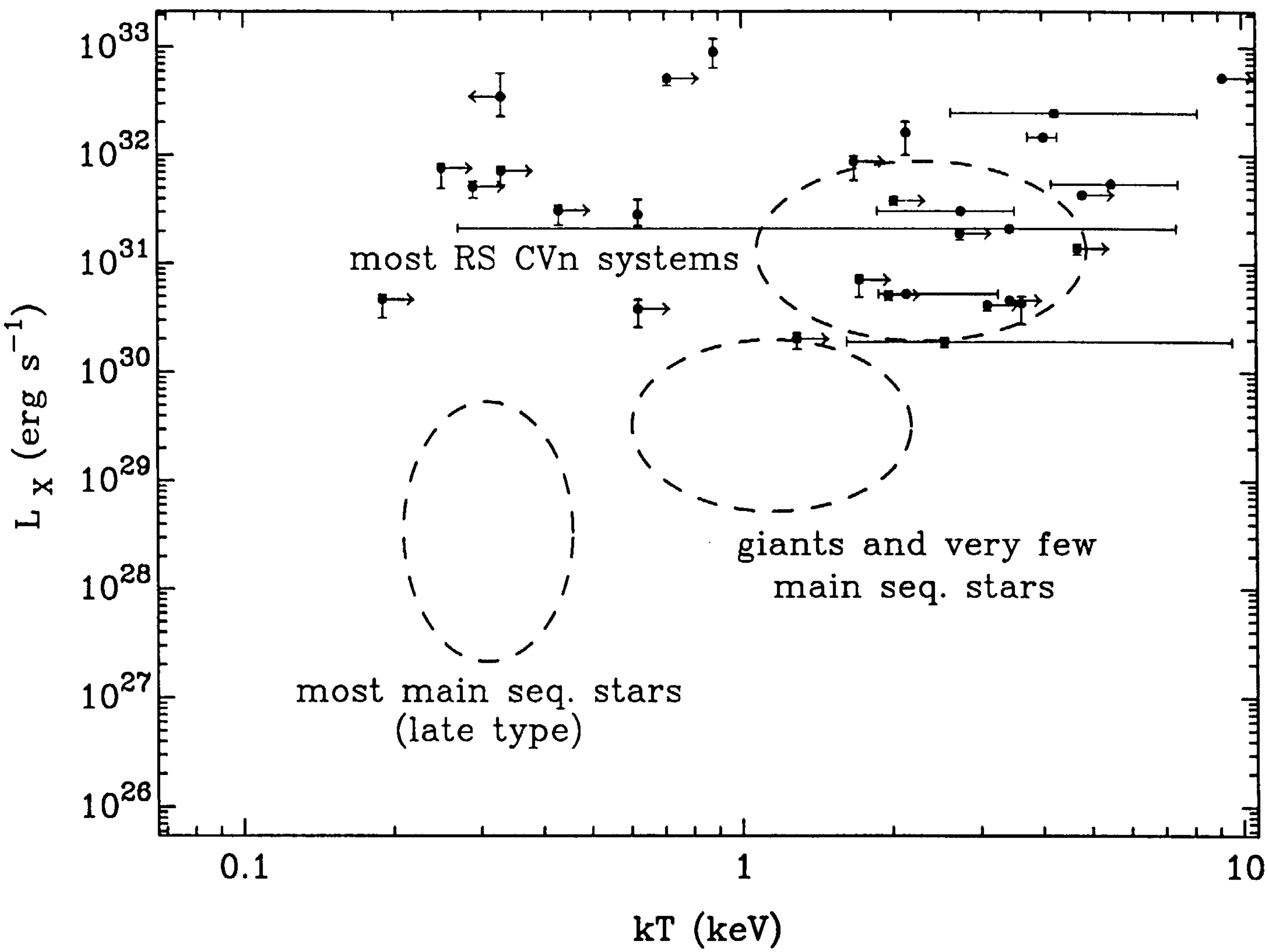


Fig. 2 (continued)



10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
10^{28}
10^{27}
10^{26}
L_X (erg s^{-1})
most RS CVn systems
giants and very few
main seq. stars
most main seq. stars
(late type)
0.1
1
10
kT (keV)

Fig. 3